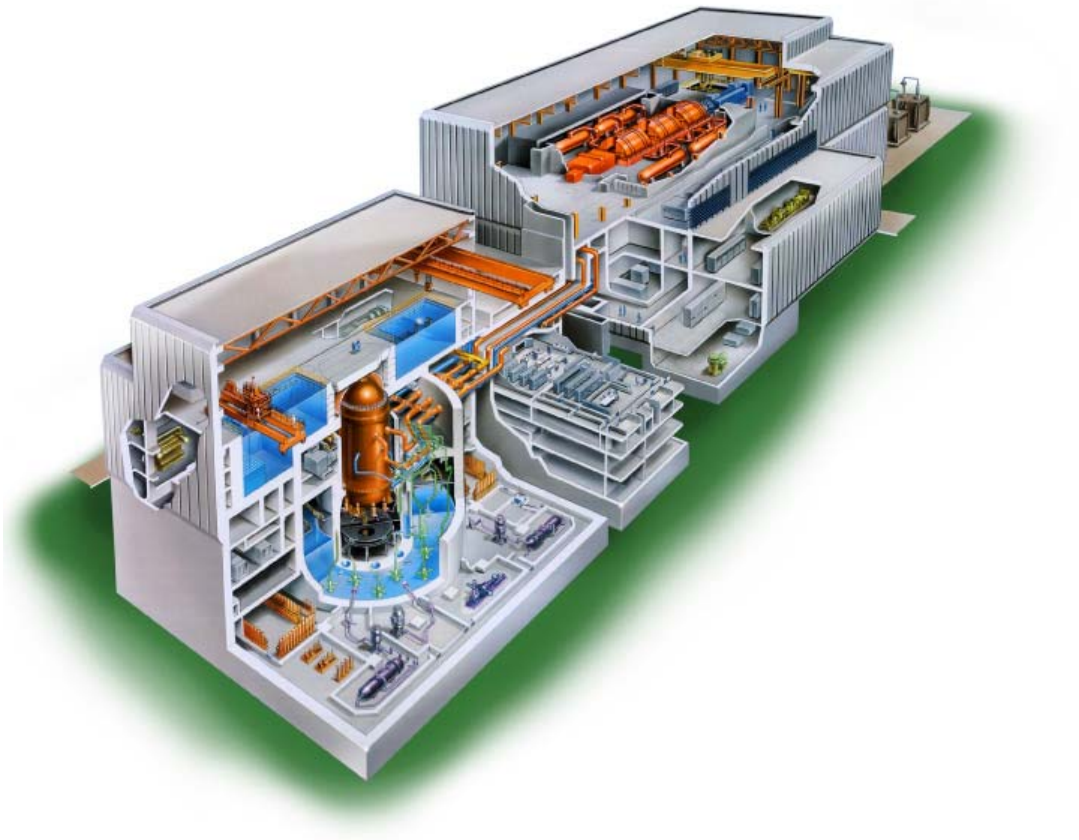
ABWR Seminar – Instrumentation & Control (I&C)



LE Fennern

April 13, 2007

ABWR Control & Instrumentation

- Key design features
- Intelligent data communication functions
- Advanced safety system design
- Advanced Nuclear Boiler process control
- Advanced Main Control Room & plant automation

Key Features

- Four divisions of Reactor Protection System (RPS) (Scram)
- Four divisions of Engineering Safety Features (e.g., ECCS)
- Four divisions of ATWS feeding two divisions of SLCS
  (Anticipated Transients Without Scram/Standby Liquid Control System)
- Triple redundant controllers for major nuclear process control
- Redundant controllers for investment protection & Balance of Plant (BOP) control

Current generation example

Control and Instrumentation Improvements

- Remote I/O & fiber optic data communication
  - Eliminates $2x10^6$ m of cables and $4000m^3$ of cable trays
- Four channel protection systems with 2/4 logic
  - Fault-tolerant & self-checking
  - Defaults to 2/3 on bypass
  - Over 40% of sensors eliminated
- Three channel control systems with voting logic
  - Fault-tolerant & self-checking
- Improved core-wide Neutron Monitoring System
  - Start-up range & Power range - all safety grade
  - Period-based protection during startup
- Automation of plant maneuvers
- Electronic on-line procedures
- Improved man-machine interface

Intelligent Data Communication Functions

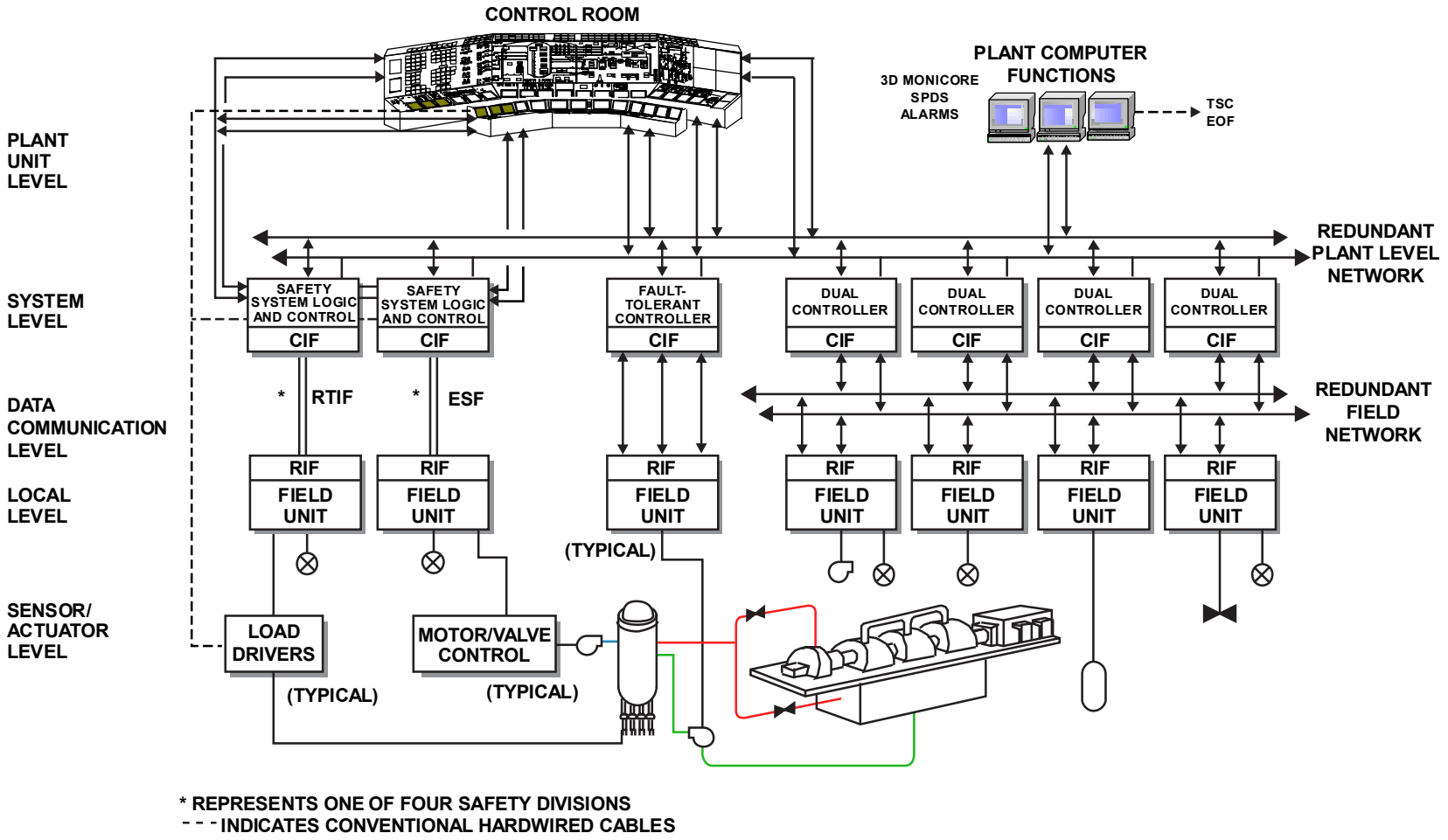
- Plant-wide, redundant, data communication functions
  - Replaces field hardwired cabling
  - Incorporated separately into both nonsafety-related and safety-related systems
  - CIF* provides isolated communication from safety-related to nonsafety-related for display purposes
  - Multiple networks maintain necessary separation
  - Intelligent remote data acquisition units
- High speed fiber optic data transmission
  - Improved electrical separation & fire protection
  - Enhanced resistance to noise (e.g., EMI)

*CIF = Control Room Interface Function

Intelligent Data Communications Network (cont'd)

- High reliability and maintainability
  - Self-test and diagnostics
  - Redundant, fault tolerant networks
- Based upon established ABWR technology design experience
  - Kashiwazaki 6 & Kashiwazaki 7
  - Lungmen 1 & 2

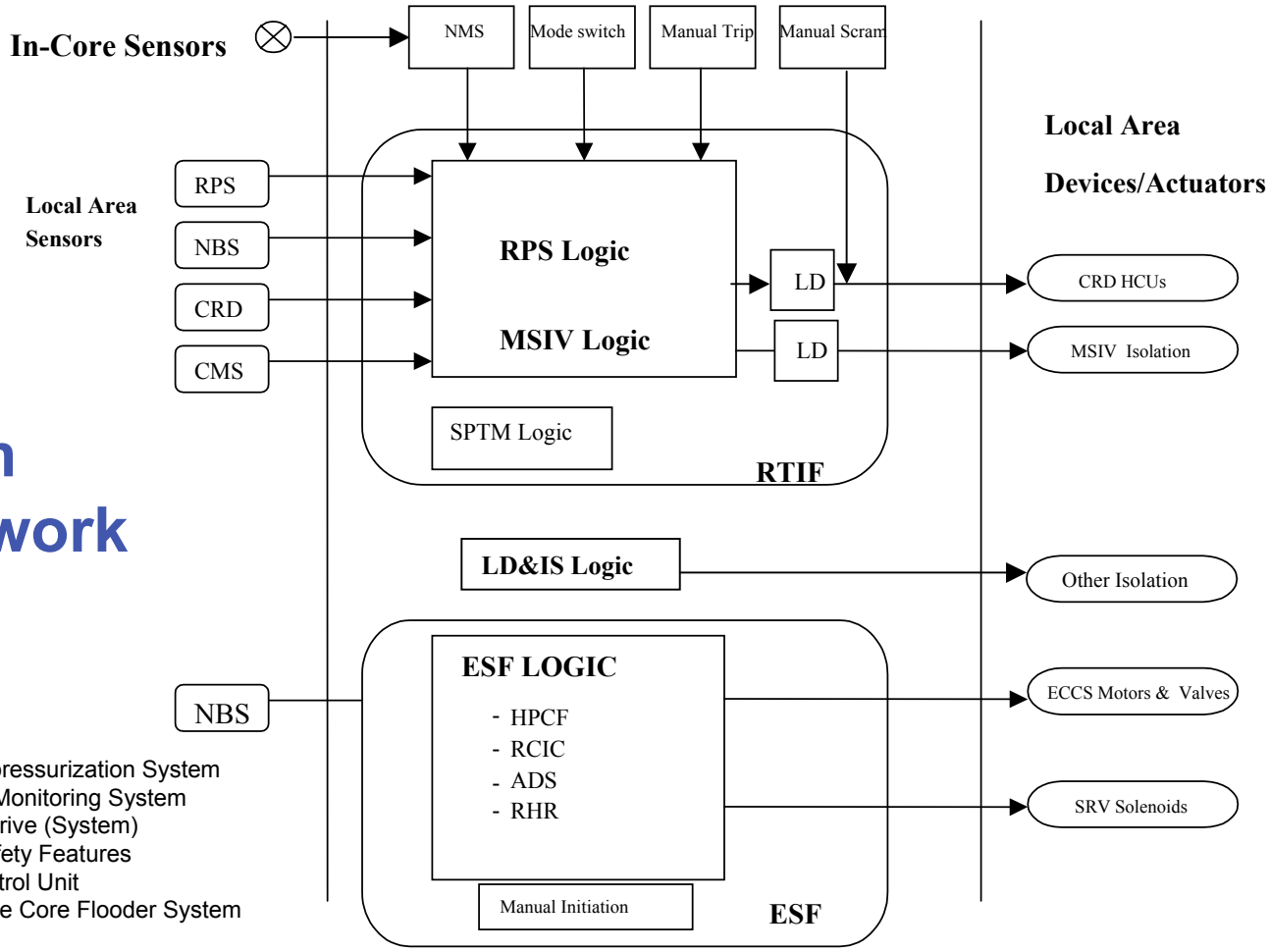
ABWR I&C Systems Architecture



Advanced Safety System Design

- Safety System Logic & Control (SSLC)
  - Integrates reactor trip, isolation, & core cooling functions
  - Four essential divisions
- Microprocessor based logic & interlock processing
  - Efficient implementation
  - Enhanced surveillance testing
- 2/4 logic design
  - Employs sensor inputs from all four divisions for 2/4 logic at sensor level
  - Single channel trip does not cause “Half Scram”
  - Sensor bypass capability to 2/3 logic, provides on-line repair capability

SSLC System Framework



ADS = Automatic Depressurization System
CMS = Containment Monitoring System
CRD = Control Rod Drive (System)
ESF= Engineered Safety Features
HCU = Hydraulic Control Unit
HPCF = High Pressure Core Flooder System
LD = Load Driver
LD&IS = Leak Detection & Isolation System
MSIV = Main Steam Isolation Valve
NBS = Nuclear Boiler System
NMS = Neutron Monitoring System
RCIC = Reactor Core Isolation Cooling System
RHR = Residual Heat Removal System
RPS = Reactor Protection System
RTIF = Reactor Trip & Isolation Function
SPTM = Suppression Pool Temperature Monitoring
SRV = Safety Relief Valve

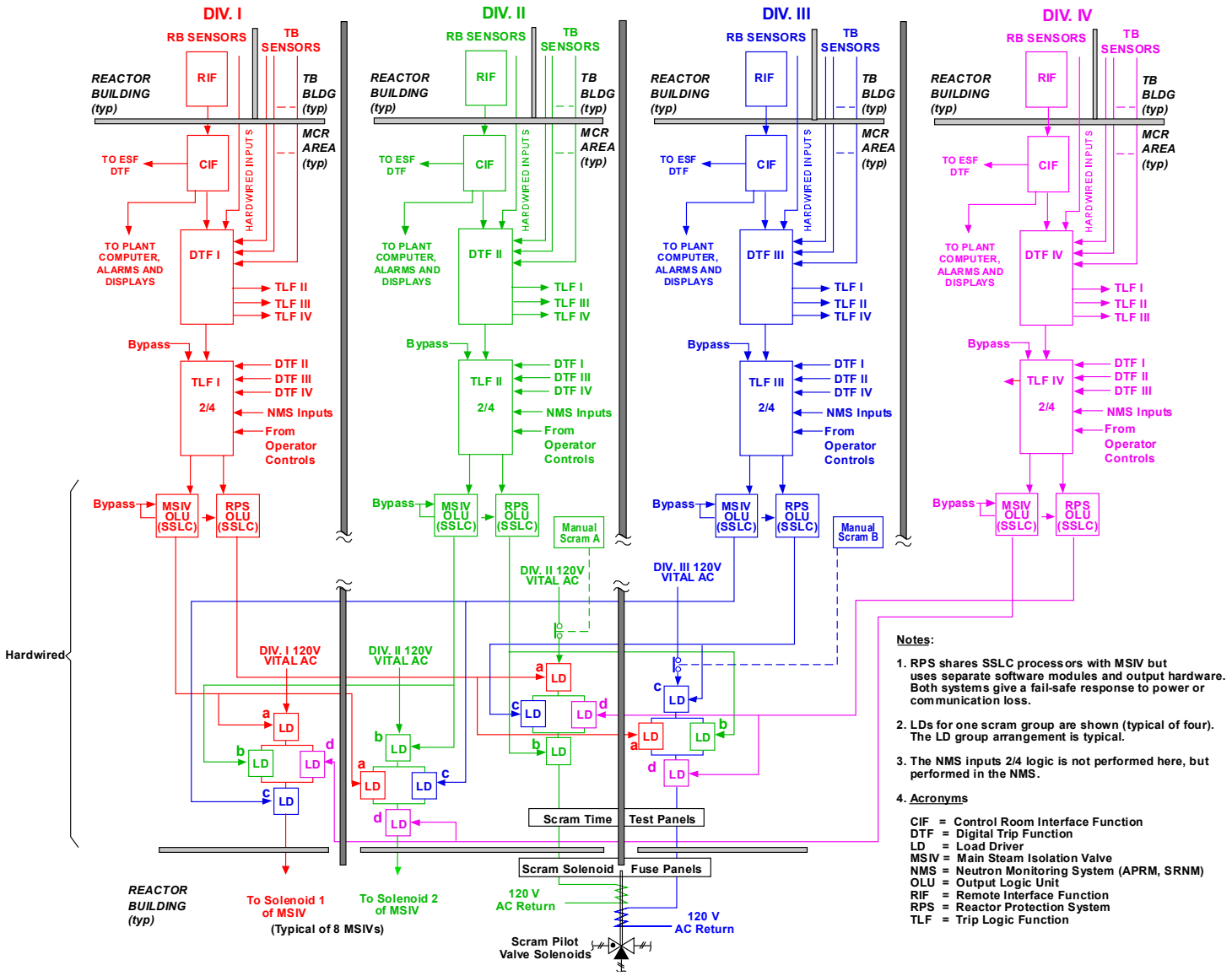
1. Local area sensors include:
   RPS: turbine stop valve position, turbine CV oil pressure, turbine bypass valve position, APRMs, SRNMs
   NBS: MSIV position (for RTIF only), RPV pressure, water level
   CRD: HCU accumulator charging water header pressure
   CMS: drywell pressure
2. Manual Scram interrupts power to the circuit.
3. LD&IS resides in SSLC and shares sensors inputs with RTIF and ESF

Safety System Logic Control (SSLC) Framework

Each Subsystem has 4 digital safety-related Divisions (Class 1E)
RPS is independent and separate from ESF Logics

- Reactor Protection System (RPS)
  - Basic design
    - » 2/4 logic
    - » Fail safe
    - » Deterministic
    - » Diverse from ECCS
  - Any two unbypassed same parameters exceeding limits always cause Scram with:
    - » Any single logic failure
    - » Any division of sensors bypass status
    - » Any division of logic bypass status (independent from sensor bypass)
    - » Any single power failure
    - » Any possible Main Control Room RPS control configuration
  - Each division makes a per parameter trip decision
  - Each division makes a 2/4 per parameter decision to Scram
  - Each division informs other divisions of divisional data (via communication module)
  - Two sets of load drivers – each driven by four divisional trip outputs – control HCU Scram solenoids

SSLC-RPS Functional Block Diagram



Notes:

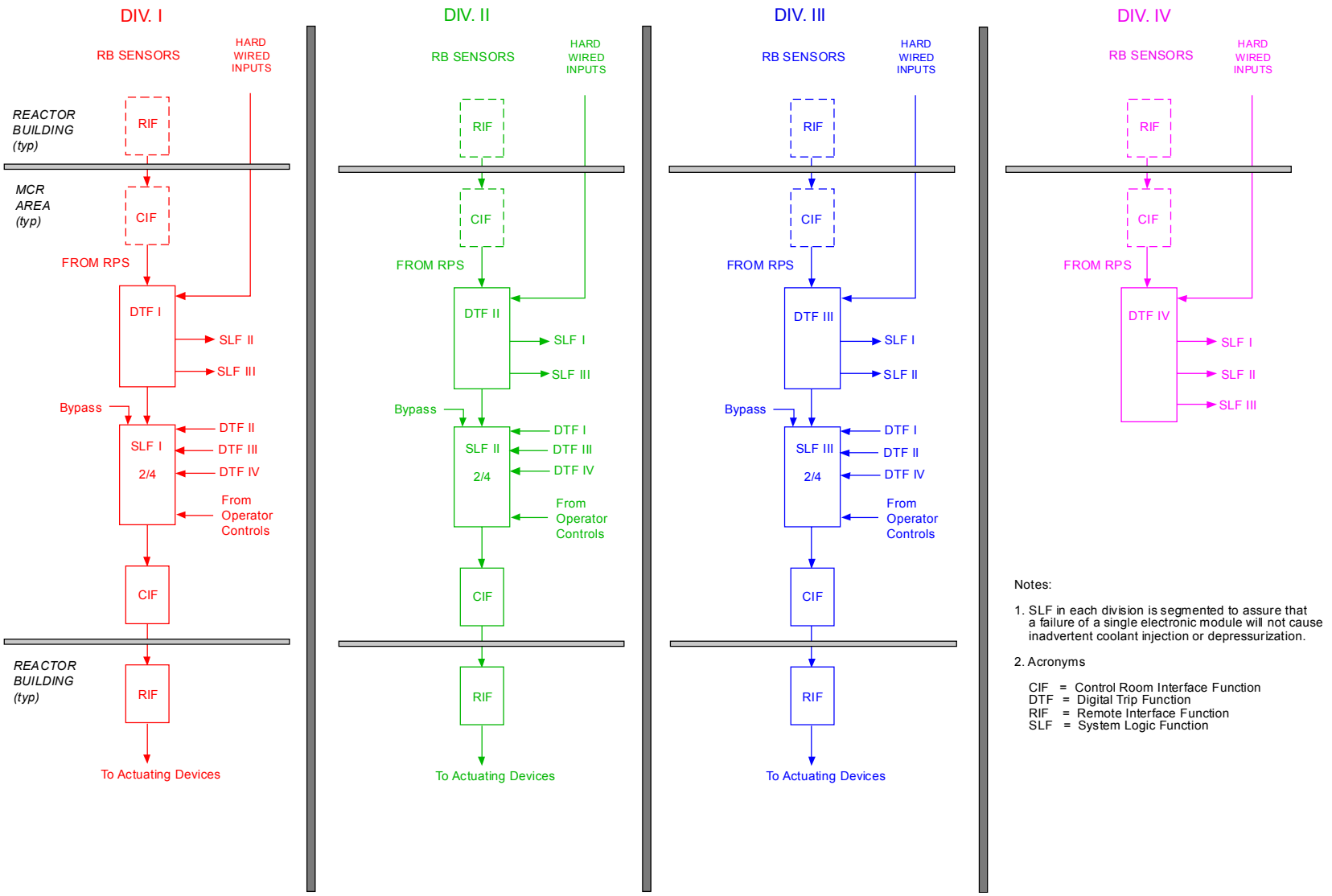
1. RPS shares SSLC processors with MSIV but uses separate software modules and output hardware. Both systems give a fail-safe response to power or communication loss.
2. LDs for one scram group are shown (typical of four). The LD group arrangement is typical.
3. The NMS inputs 2/4 logic is not performed here, but performed in the NMS.
4. Acronyms

CIF = Control Room Interface Function
DTF = Digital Trip Function
LD = Load Driver
MSIV = Main Steam Isolation Valve
NMS = Neutron Monitoring System (APRM, SRNM)
OLU = Output Logic Unit
RIF = Remote Interface Function
RPS = Reactor Protection System
TLF = Trip Logic Function

Safety System Logic Control (SSLC) Framework (cont'd)

- Engineering Safety Features Logics (SSLC/ESF)
  - Basic design
    - » 2/4 logic
    - » Fail As-Is
    - » Deterministic
    - » Diverse from RPS
  - Any two unbypassed same parameters exceeding limits always initiate ECCS with:
    - » Any single logic failure
    - » Any division of sensors bypass status
    - » Any single power failure
  - Each division makes a per parameter trip decision
  - Each division makes a 2/4 per parameter decision to initiate
  - Each division informs other divisions of divisional data (via communication module)
  - Design single failure proof to prevent inadvertent injection or depressurization

SSLC-ESF Functional Block Diagram



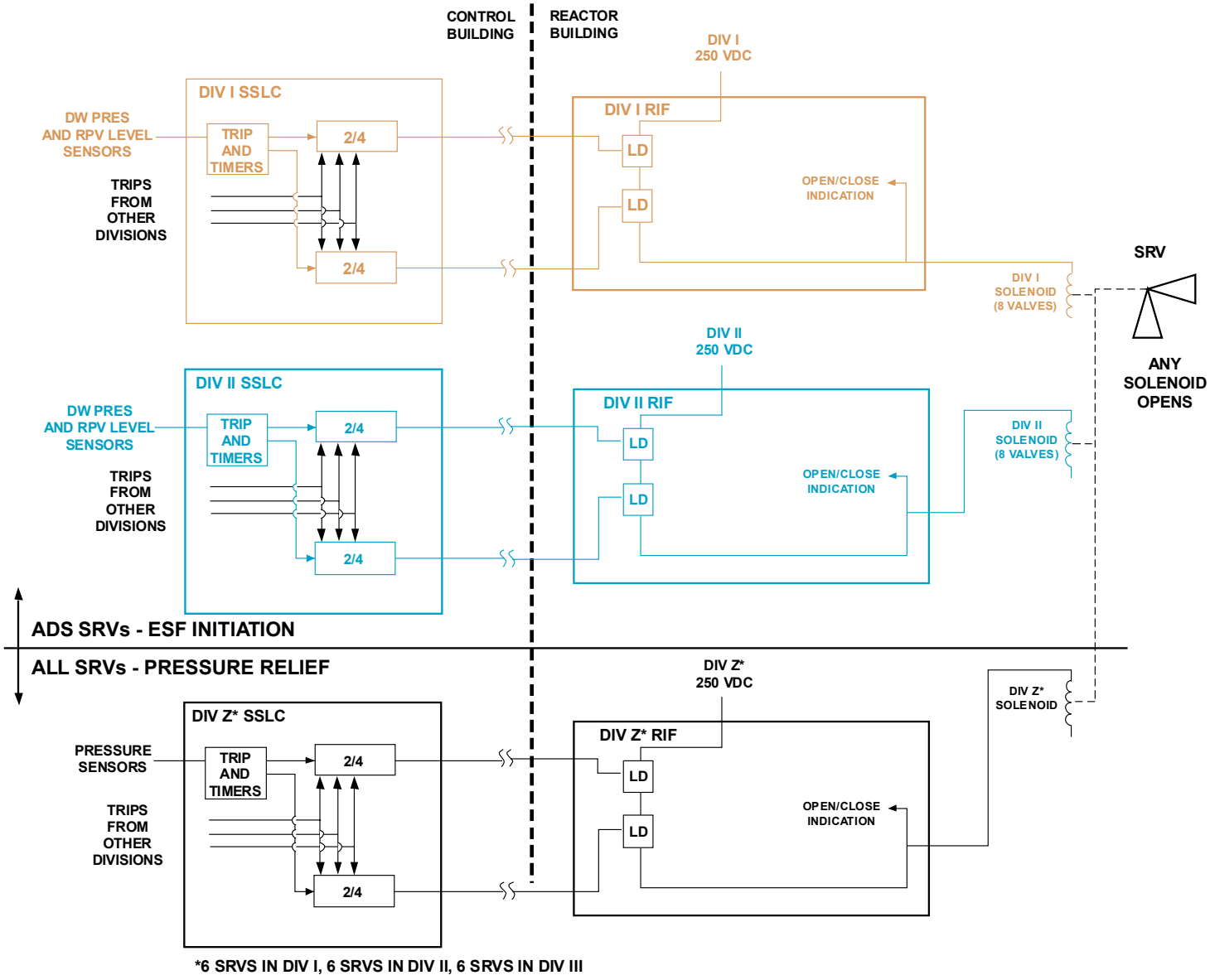
Notes:

1. SLF in each division is segmented to assure that a failure of a single electronic module will not cause inadvertent coolant injection or depressurization.

2. Acronyms

   CIF = Control Room Interface Function
   DTF = Digital Trip Function
   RIF = Remote Interface Function
   SLF = System Logic Function

SSLC/ESF SRV Initiation Logic



*6 SRVS IN DIV I, 6 SRVS IN DIV II, 6 SRVS IN DIV III

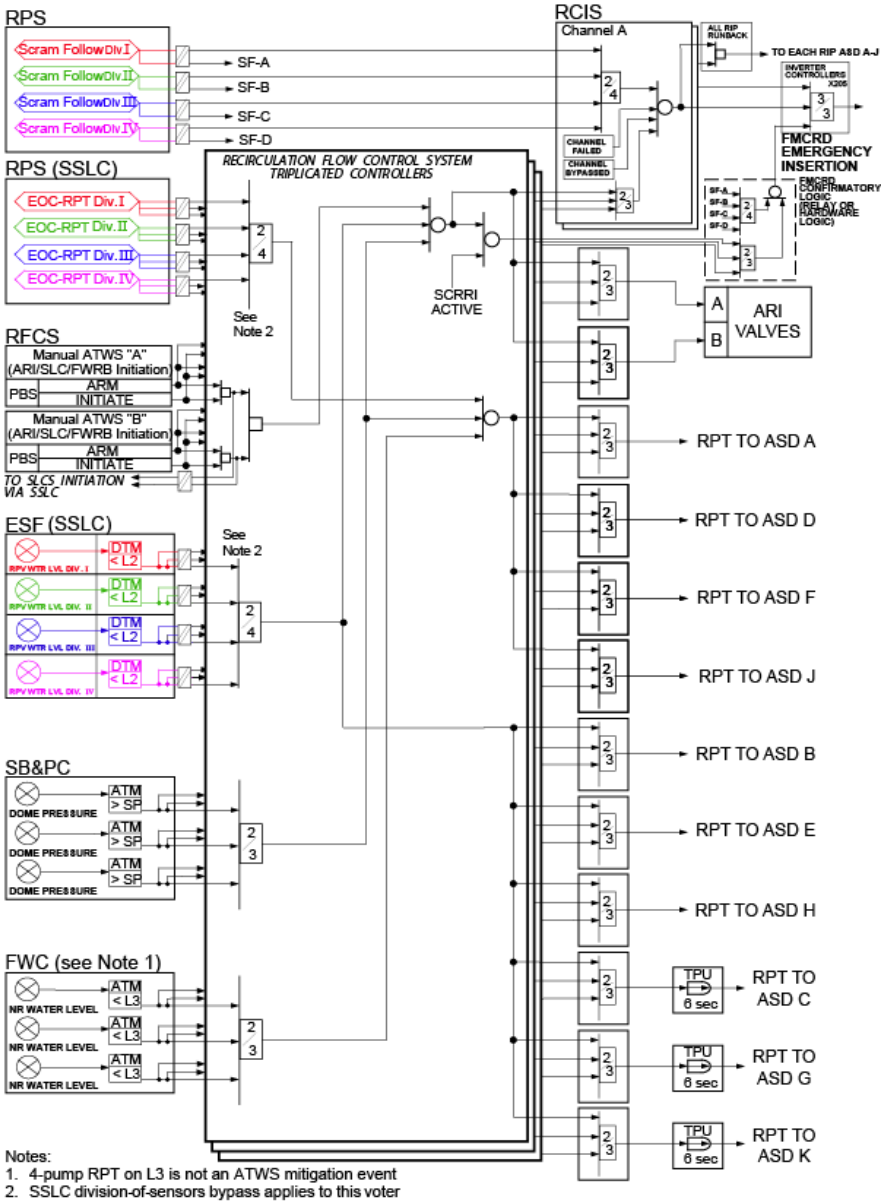
Safety System Logic Control (SSLC) Framework (cont'd)

- Leak Detection and Isolation System (LDIS)
  - 4 divisions
  - Monitors leakage in the following systems and isolates systems or containment if necessary
    - » Main Steam
    - » Reactor Water Cleanup
    - » Residual Heat Removal
    - » Reactor Core Isolation Cooling
    - » Feedwater
    - » Other ECCS
    - » Other miscellaneous systems

Anticipated Transient Without Scram

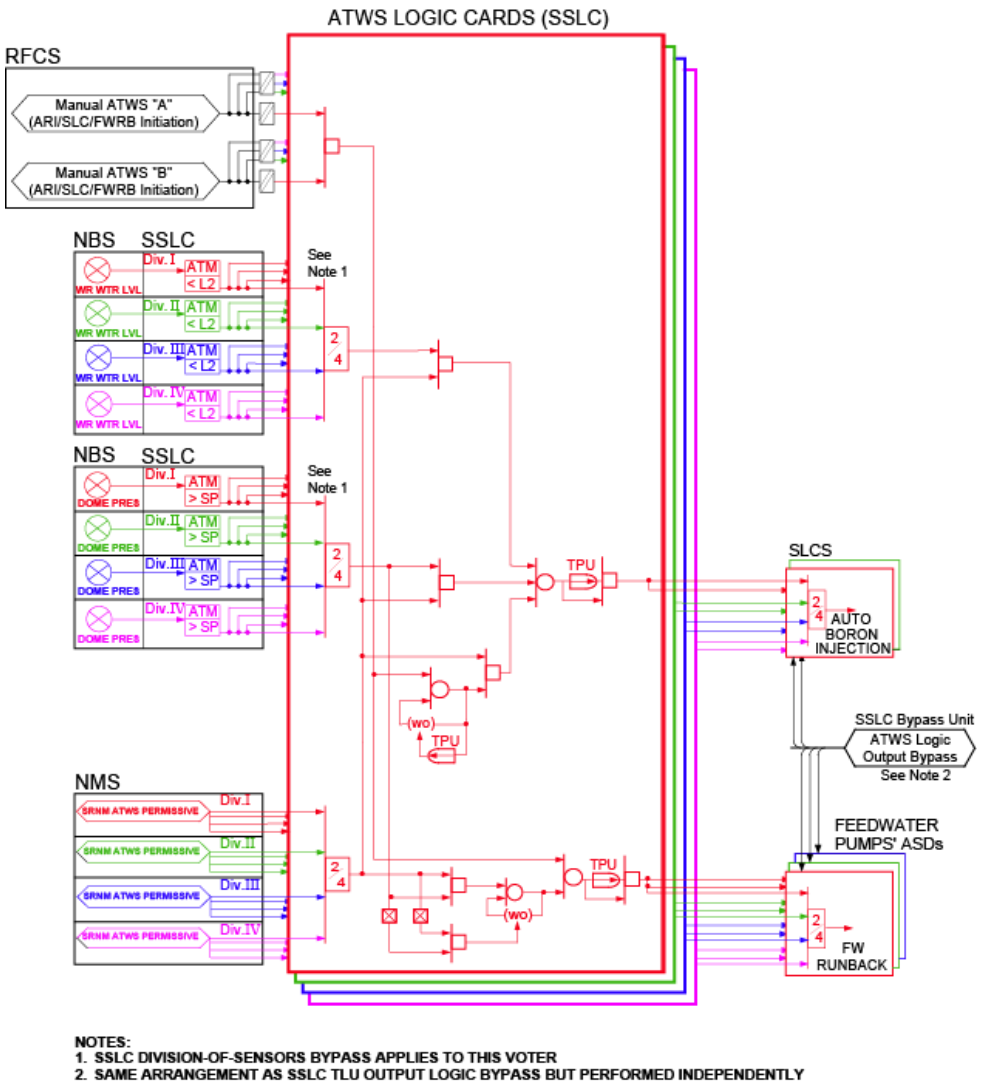
- Redundant logic
  - Backup Scram signals to rods
  - Recirculation Pump speed trip/runback
  - Standby Liquid Control Injection Initiation
  - Feedwater runback

ATWS Logic - RPT



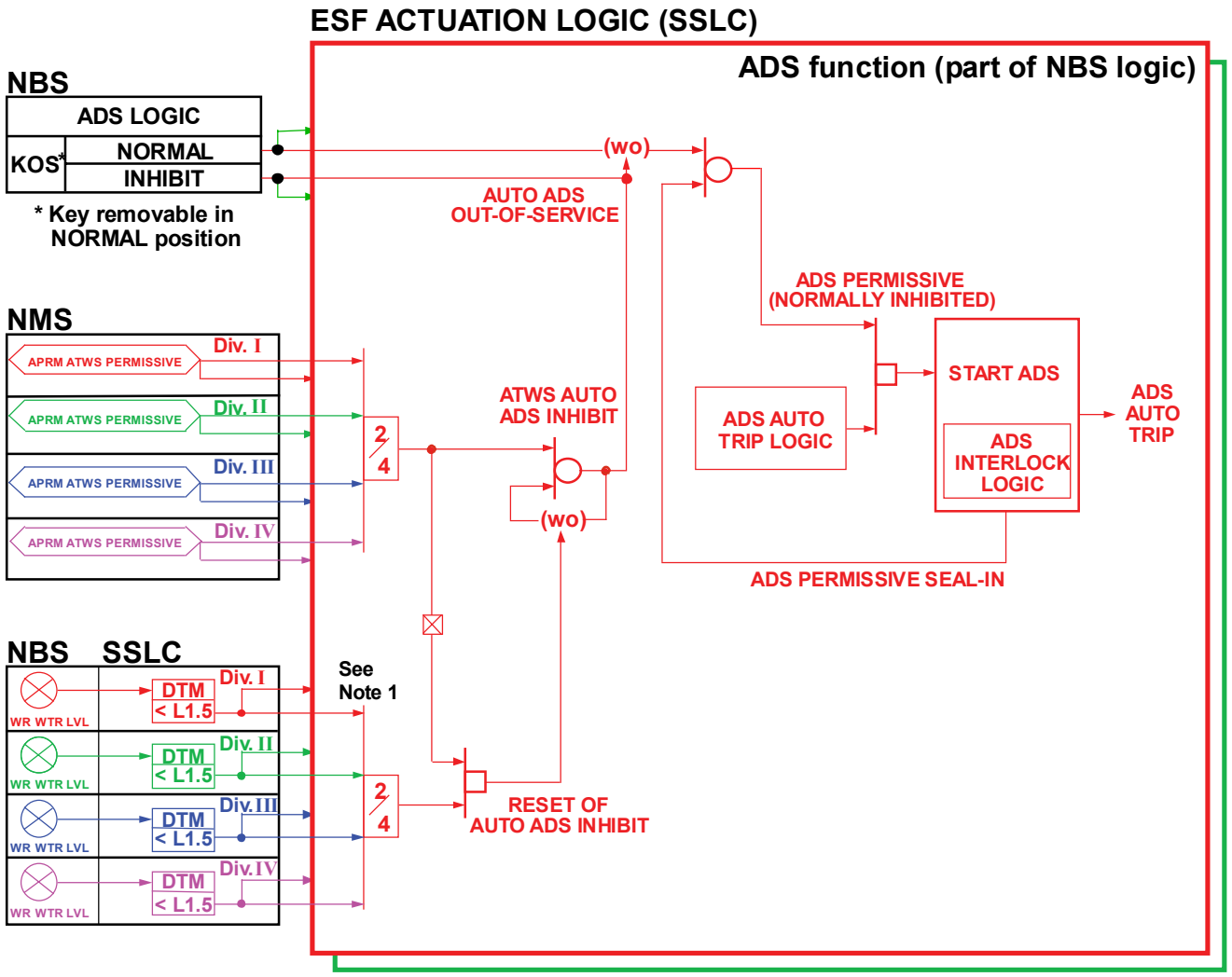
Notes:
1. 4-pump RPT on L3 is not an ATWS mitigation event
2. SSLC division-of-sensors bypass applies to this voter

ATWS Logic – SLCS and Feedwater



NOTES:
1. SSLC DIVISION-OF-SENSORS BYPASS APPLIES TO THIS VOTER
2. SAME ARRANGEMENT AS SSLC TLU OUTPUT LOGIC BYPASS BUT PERFORMED INDEPENDENTLY

ATWS Logic – ADS Inhibit



NOTES:
1. SSLC DIVISION-OF-SENSORS BYPASS APPLIES TO THIS VOTER

Neutron Monitoring System (NMS)

NMS is comprised of 4 subsystems:

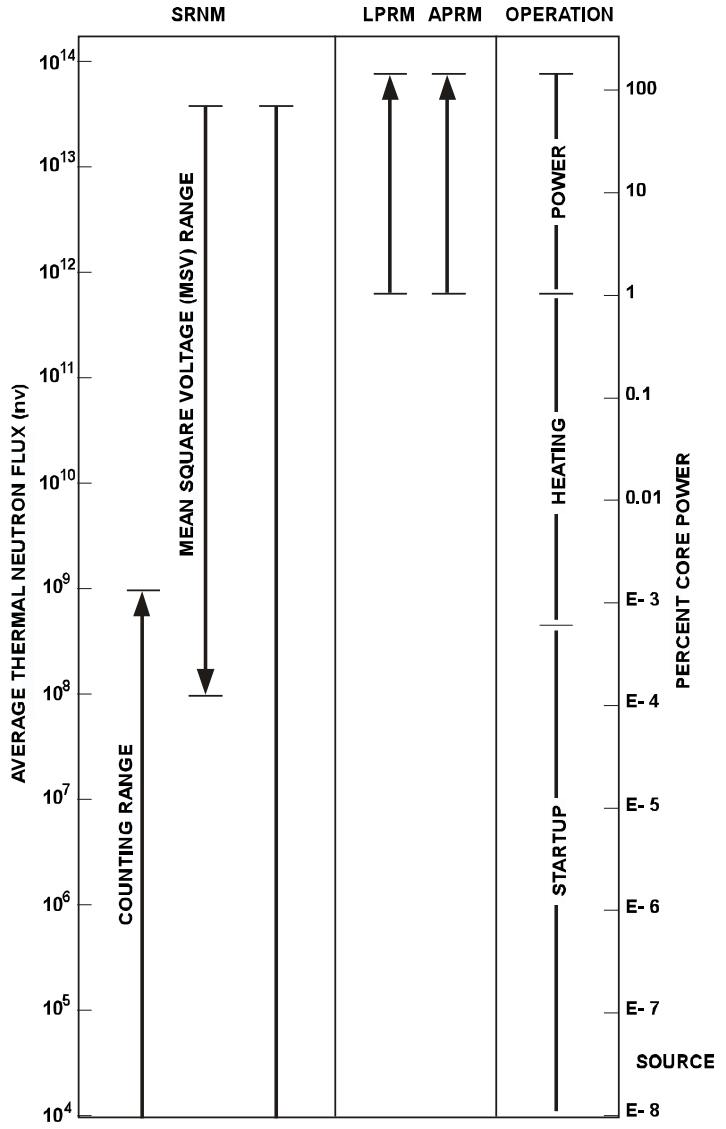
- Safety-related
  - Startup Range Neutron Monitoring (SRNM)
  - Power Range Neutron Monitoring (LPRM and APRM)
- Non safety-related
  - Automated Traversing In-Core Probe (ATIP)
  - Multi-channel Rod Block Monitoring (MRBM)

SRNM and PRNM Subsystems

- SRNM
  - 10 fixed detectors
  - Covers from source range to >15% power
  - Inputs flux and period information to RCIS*, APR, RPS and ATWS
    - » Manual range switches of previous designs eliminated
- PRNM
  - LPRMs - 52 locations, each with 4 elevations
  - LPRMs divided into 4 groups for APRM subsystem
  - Each APRM group chosen to represent average core power
  - Inputs flux information to RCIS, APR, RPS and ATWS
  - Oscillation Power Range Monitoring (OPRM) checks for reactor instabilities

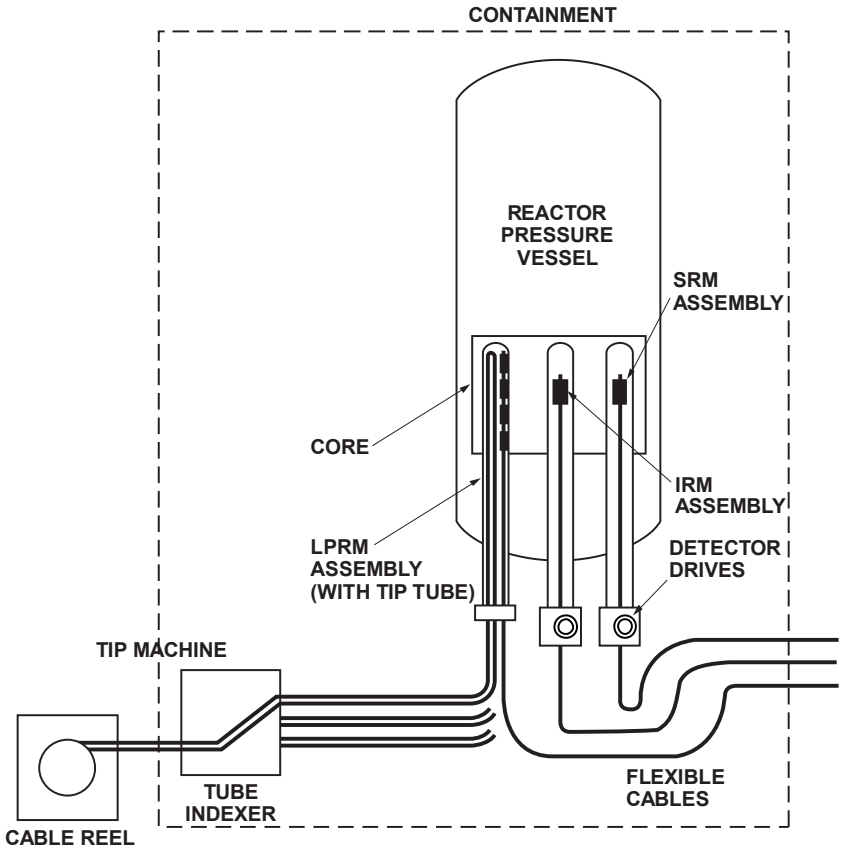
* Rod Control and Information System

ABWR Ranges of Neutron Monitoring Systems

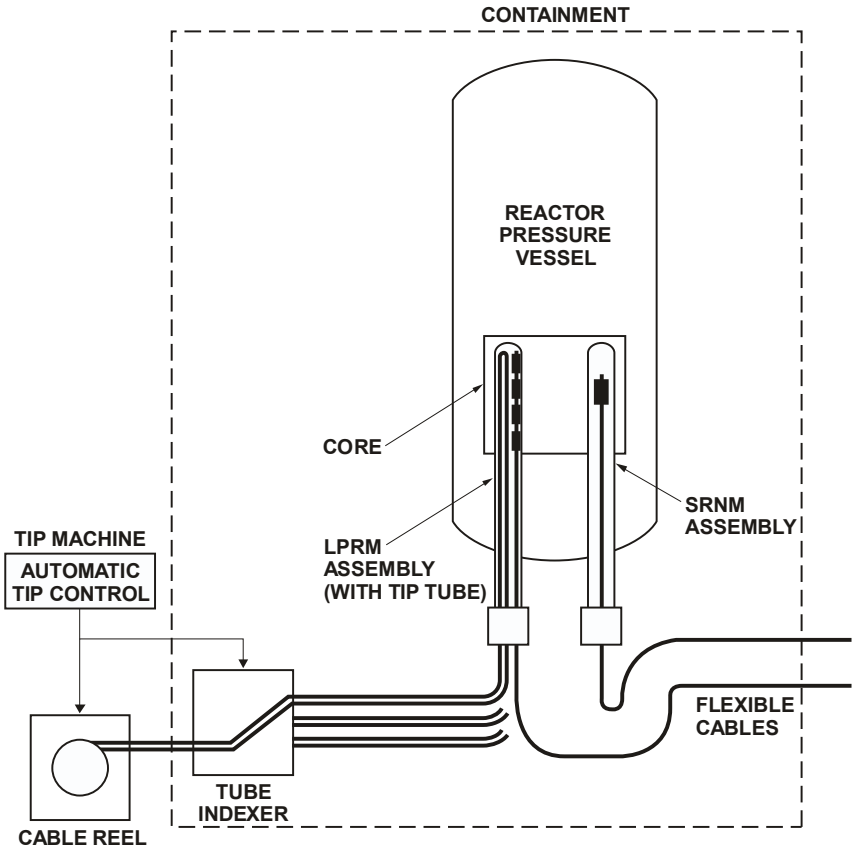


SRNM = Startup Range Neutron Monitor
LPRM = Local Power Range Monitor
APRM = Average Power Range Monitor

Neutron Monitoring System Improvements

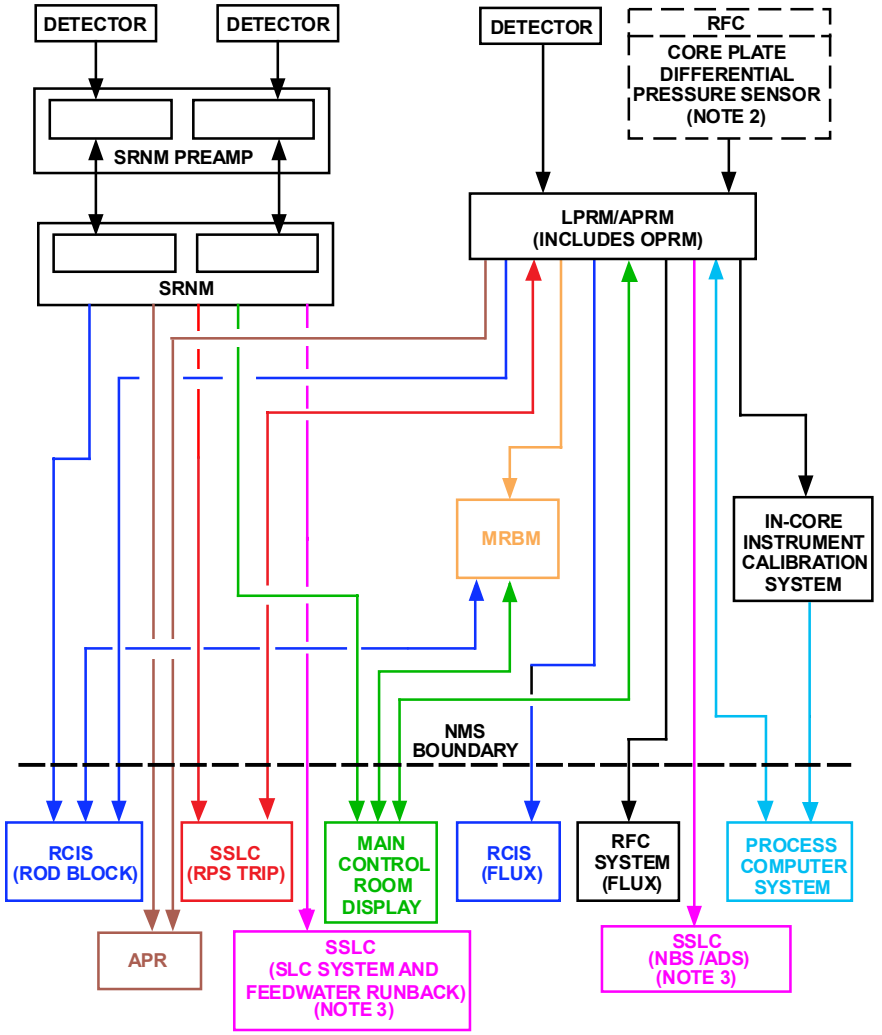


Conventional BWR



ABWR

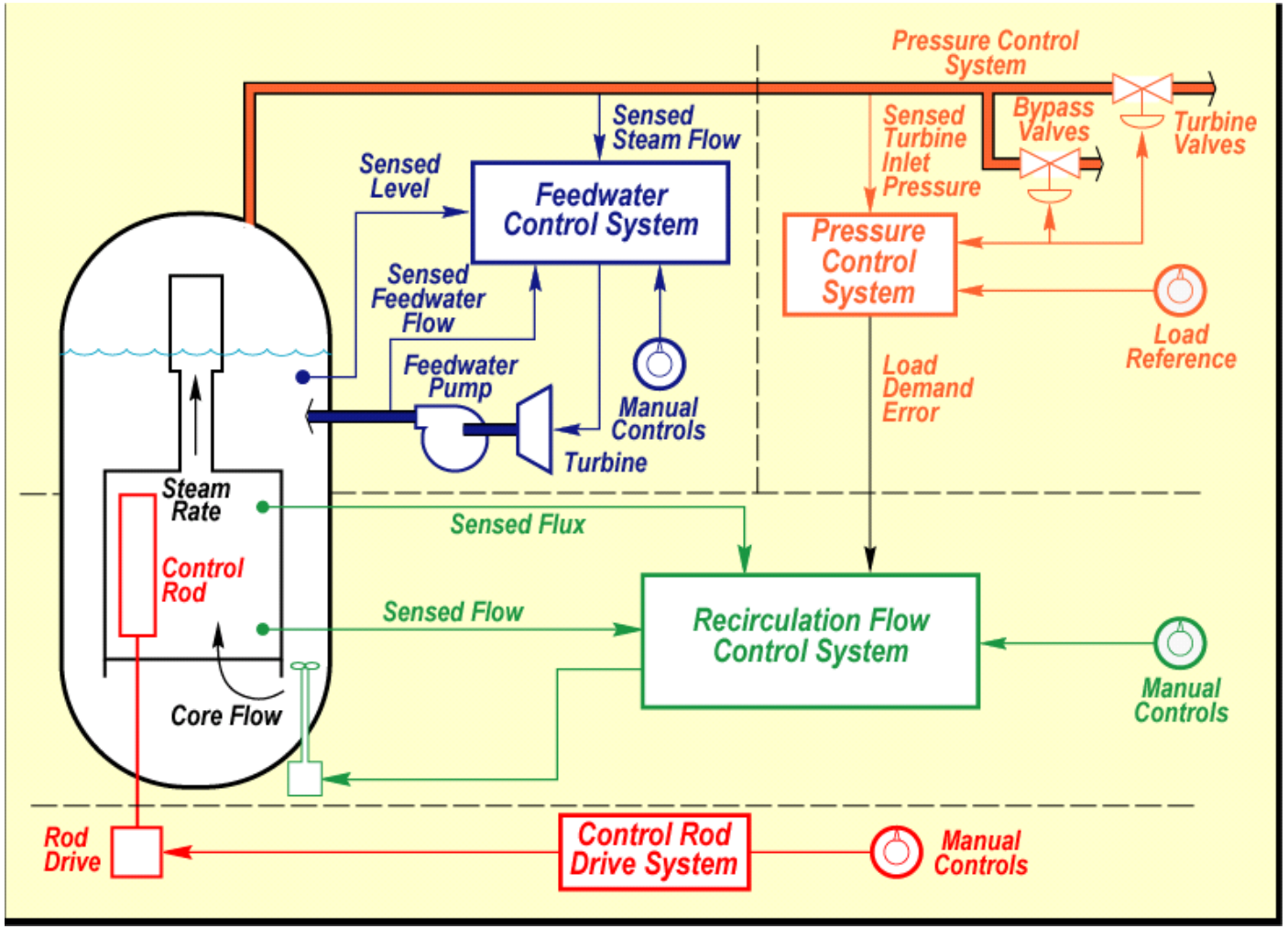
Neutron Monitoring System Schematic



NOTES:

1. DIAGRAM REPRESENTS ONE OF FOUR NMS DIVISIONS (MRBM IS A DUAL CHANNEL SYSTEM. THERE IS ONLY ONE IN-CORE INSTRUMENT CALIBRATION SYSTEM).
2. USED FOR RAPID CORE FLOW DECREASE TRIP.
3. SRNM AND APRM ATWS PERMISSIVE SIGNALS TO SSLC.
4. INTERCONNECTIONS MAY BE FIBER-OPTIC OR METALLIC.

Advanced Process Control Systems



Advanced Nuclear Boiler Process Control

- Major process control systems implemented on Fault Tolerant Digital Controllers (FTDC)
  - Feedwater Control System
  - Steam Bypass & Pressure Control System
  - Recirculation Flow Control System
  - Automatic Power Regulator System
- Triplicated microprocessor architecture
  - On-line repair capability
- Redundant communications

Advanced Nuclear Boiler Process Control (cont'd)

- Redundancy of key process inputs
- Fault tolerant output voters
  - Mid-value vote on analog outputs
  - 2/3 vote on discrete outputs
  - "Ringback" of critical outputs to detect voter failure
- Proven technology
  - Industrial controls
  - ABWR plant application
  - BWR retrofits (e.g., upgrade of turbine controls)

Advanced Process Control Systems

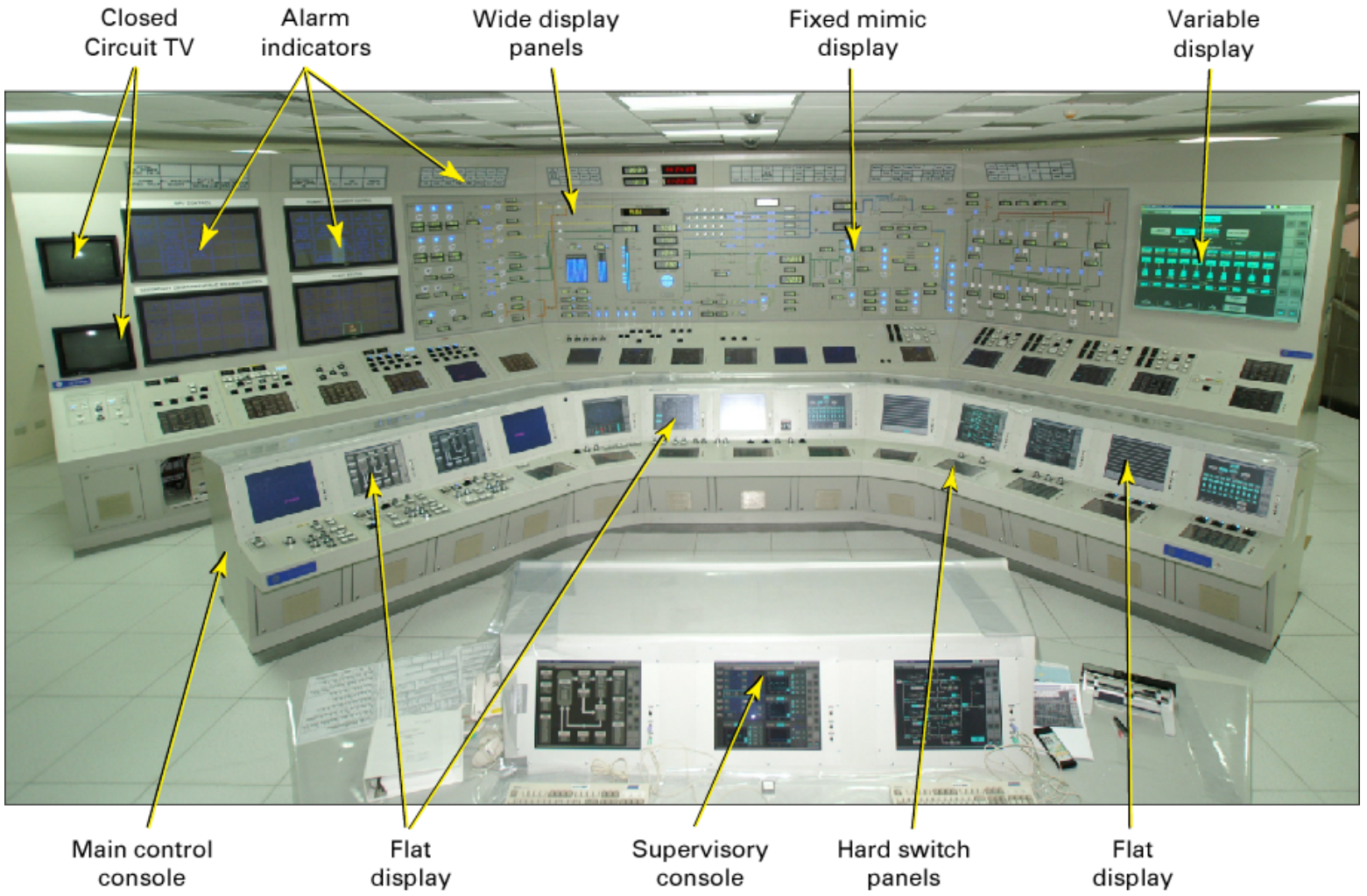
Rod Control and Information System (RCIS)

- Dual redundant
- Manual, semi-automatic and fully automatic modes
- Controls movement of control rods
- Contains two subsystems
  - Automatic Thermal Limit Monitor (ATLM)
    - » First line of defense against Rod Withdrawal Error (RWE)
    - » Blocks rod movement before OLMCPR is reached
  - Rod Worth Minimizer (RWM)
    - » Enforces rod sequencing rules
- Manages ARI, SCRRI, FMCRD run-in as required

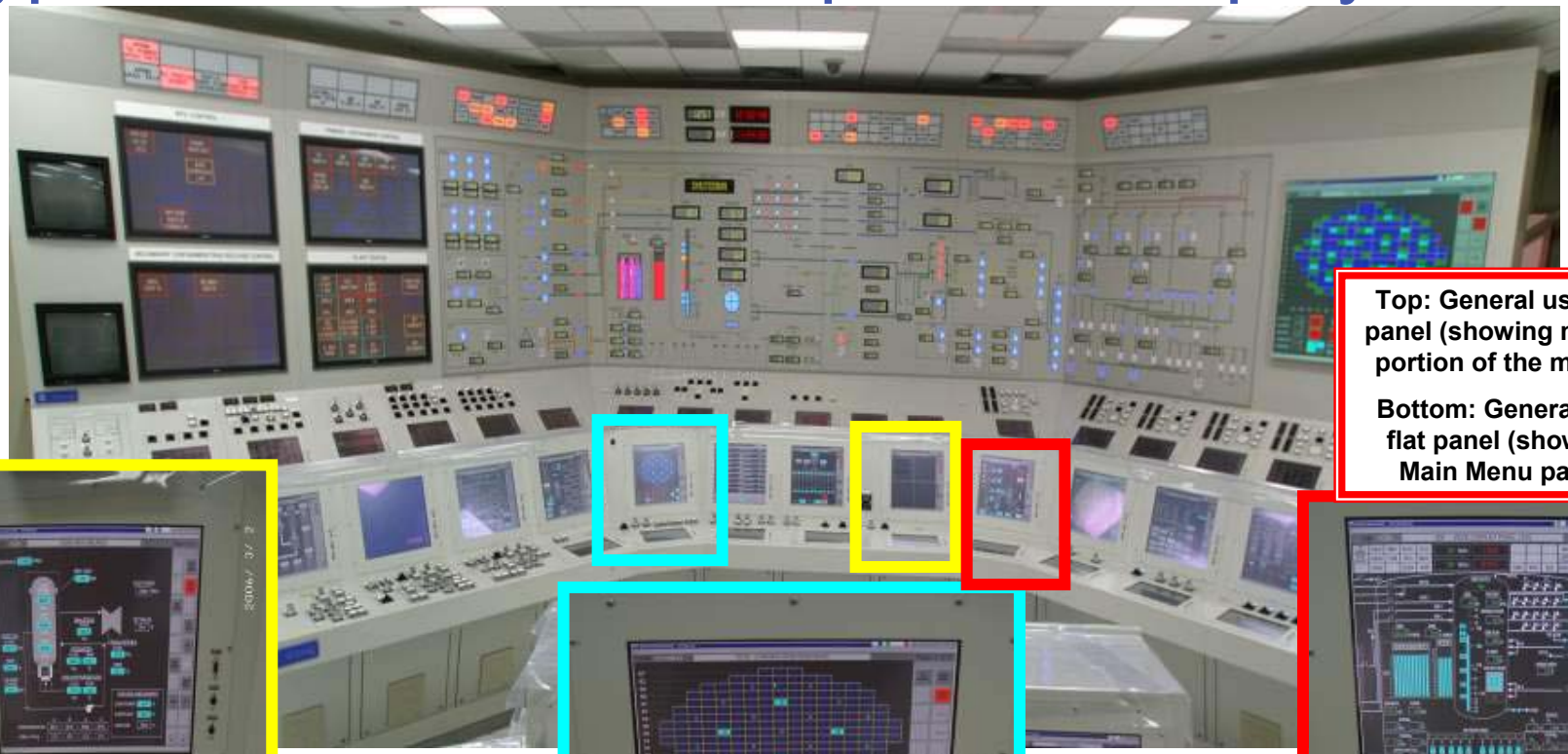
BWR Control Room Comparison

	Operating BWRs	*ABWR*
• Size	Large	Small
• Technology	Analog hardware	Digital, fiber optics
• Large Mimic Displays	None	Overall plant monitoring, industrial TVs
• Controls	Hard switches for individual equipment control	VDUs, flat control panels, system mode oriented control, limited hard switches
• Console Displays	Dedicated hardware	flat panels
• Operators (Not including supervisors)	Three (typical)	Two
• Human Factors	Retrofitted post–TMI	Integrated in design (SPDS, Procedures on CRTs)

Lungmen Control Room Simulator

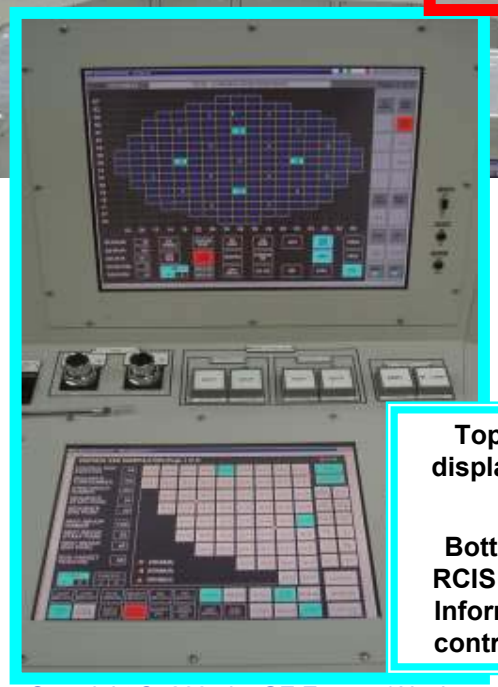


Typical Control Room Operator Displays



Top: General use flat panel (showing NSSS Heat Balance graphic)

Bottom: General use flat panel (showing Alarm page)



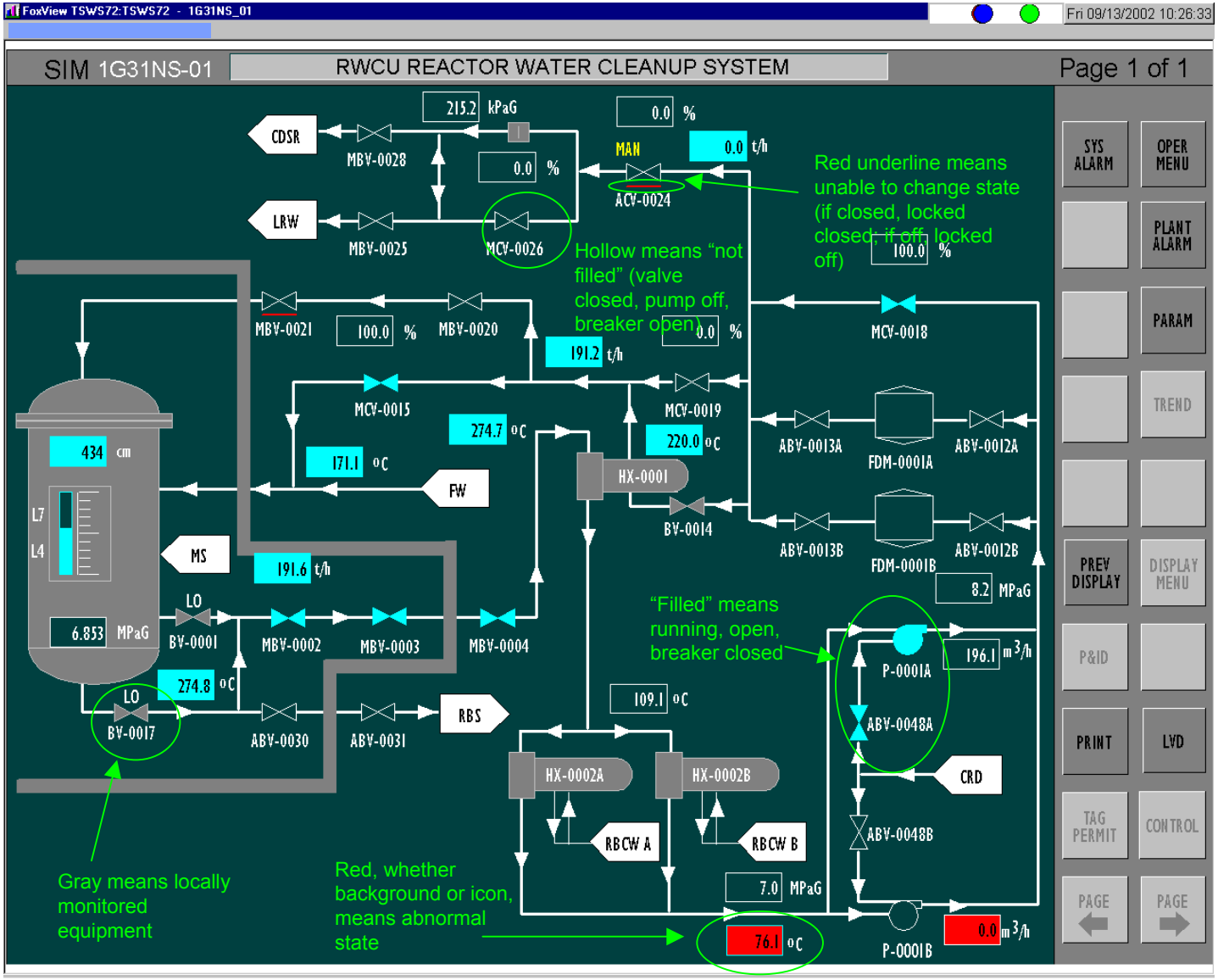
Top: General use display (showing full core map)

Bottom: Dedicated RCIS (Rod Control & Information System) controls and display

Top: General use flat panel (showing middle portion of the mimic)

Bottom: General use flat panel (showing Main Menu page)

P&ID Display – Reactor Water Cleanup



Implementation of Automated Operations

- Top level "power generation control system" (PGCS) function implemented in plant computer system
  - Based upon proven PGCS design in recent Japanese BWR plants
- Automatic mode
  - PGCS performs plant operations
  - PGCS sends mode change commands to system controllers
  - PGCS provides prompts when operator action (“acknowledgment”) required
  - Operator controls status of safety system
  - Operator monitors & controls continued progression of automation operations
- Semi-automatic mode
  - PGCS monitors plant operations & provides guidance
- Manual mode

Implementation of Automated Operations (cont'd)

- Operator can start/stop automated operation at anytime
- Operation automatically reverts to Manual mode in event of major plant upset (e.g., SCRAM)
- Individual systems monitor operational status & revert to manual if failure detected

Summary of ABWR I&C Characteristics

- Fault tolerant designs – reduced chance of failure or operator error leading to an outage
- ABWR digital I&C design has been in operation & in construction
- Minimized hardwired cables/utilized fiber optics
- Proven system & hardware/software designs
- Automation implemented